

## CLAIMS

What is claimed is:

- 1        1. A method of plasma treatment of substrates comprising:
  - 2            (a) positioning a plasma generating electrode adjacent to an exposed surface of a substrate;
  - 4            (b) establishing a selected pressure of a selected gas over the plasma generating electrode and the substrate surface; and
  - 6            (c) applying a voltage to the plasma generating electrode to establish a plasma in the selected gas that is localized in a region between the electrode and the adjacent exposed surface of the substrate for a selected period of time to plasma treat the substrate, wherein the localized region in which the plasma is established is less than the entire surface of the substrate and the gas pressure established over the substrate and electrode is at least 1 torr and the electrode is positioned sufficiently close to the substrate surface that the plasma is established by applying a voltage to the electrode at a voltage level that does not result in arcing.
- 1        2. The method of Claim 1 wherein, after establishing the plasma in the region between the electrode and the substrate for the selected period of time, then moving the electrode to another position adjacent to the surface of the substrate, establishing a selected gas pressure of a selected gas over the electrode and the substrate, and applying a voltage to the electrode to establish a plasma that is localized in a region between the electrode and the substrate to plasma treat the substrate wherein the localized region in which the plasma is established is less than the entire surface of the substrate.
- 1        3. The method of Claim 1 wherein the plasma generating electrode comprises at least two separate electrode segments which are spaced from each other.
- 1        4. The method of Claim 1 wherein the electrode is positioned to be spaced within 1,000 µm of the substrate surface.

1               5.     The method of Claim 4 wherein the electrode is spaced less  
2     than 50  $\mu$ m from the substrate surface.

1               6.     The method of Claim 1 wherein the plasma is established to  
2     remove material from the substrate.

1               7.     The method of Claim 1 wherein the plasma is established to  
2     add material from the plasma to the substrate.

1               8.     The method of Claim 1 wherein the plasma is established by  
2     applying a DC voltage between the electrode and the substrate surface sufficient to  
3     generate a plasma in the region between the electrode and the substrate surface  
4     without arcing and to draw positively charged ions toward the substrate surface.

1               9.     The method of Claim 1 wherein the plasma is established by  
2     applying an AC voltage to the electrode sufficient to generate a plasma in the region  
3     between the electrode and the substrate surface without arcing.

1               10.    The method of Claim 1 including the step of moving the  
2     electrode across the substrate surface while establishing a plasma between the  
3     electrode and the substrate.

1               11.    The method of Claim 1 wherein the substrate is a silicon  
2     wafer, and wherein in the step of applying a voltage to the electrode, a conductive  
3     plate is applied to the silicon wafer on a surface thereof opposite to the surface to be  
4     treated and a voltage source is connected to the electrode and the conductive plate to  
5     provide the voltage between the electrode and the substrate.

1               12.    The method of Claim 1 wherein the step of positioning the  
2     plasma generating electrode comprises applying a dielectric layer having at least one  
3     opening therein on the substrate surface and applying the plasma generating  
4     electrode to the dielectric layer adjacent to the opening in the dielectric layer and  
5     adjacent to the surface of the substrate exposed by the dielectric layer.

1           13. The method of Claim 12 further including applying a second  
2 electrode on the substrate surface, which is between the dielectric layer and the  
3 substrate surface, and the step of applying voltage comprises applying voltage  
4 between the plasma generating electrode and the second electrode.

1           14. The method of Claim 12 including after applying a voltage to  
2 plasma treat the substrate for a selected period of time, removing the dielectric layer  
3 and the plasma generating electrode from the substrate.

1           15. The method of Claim 14 wherein the step of removing is  
2 carried out by dissolving the dielectric layer and the electrode in liquid etchant

1           16. The method of Claim 1 wherein the plasma generating  
2 electrode is a first plasma generating electrode, and including the step of positioning  
3 at least one additional plasma generating electrode adjacent to an exposed surface of  
4 the substrate while establishing a selected pressure of the selected gas over the  
5 additional plasma generating electrode and the substrate, and applying a voltage to  
6 the additional plasma generating electrode to establish a plasma in the selected gas  
7 that is localized in a region between the additional electrode and the adjacent  
8 exposed surface of the substrate for a selected period of time to plasma treat the  
9 substrate such that the localized region in which the plasma is established is less  
10 than the entire surface of the substrate and is separated from the localized plasma in  
11 the region of the first plasma of electrode.

1           17. The method of Claim 1 wherein positioning the plasma  
2 generating electrode comprises applying a dielectric layer to the substrate surface  
3 and applying the plasma generating electrode to the dielectric layer, and further  
4 applying another dielectric layer with a second electrode thereon to the substrate  
5 such that the second electrode is spaced from the plasma generating electrode with  
6 the exposed substrate surface lying between the electrodes and wherein the step of  
7 applying a voltage comprises applying a voltage between the plasma generating  
8 electrode and the second electrode

1           18. The method of Claim 17 further including applying a bottom  
2 electrode layer on the substrate under the dielectric layers and the plasma generating  
3 electrode and the second electrode and electrically biasing the bottom electrode  
4 layer to drawn ions from the plasma toward the substrate surface.

1           19. The method of Claim 17 further including applying at least  
2 one control electrode to the substrate surface between the plasma generating  
3 electrode and the second electrode and selectively biasing the control electrode to  
4 selectively attract or repel ions in the plasma.

1           20. The method of Claim 19 wherein the control electrode has at  
2 least one opening therein that exposes the surface of the substrate to the plasmas.

1           21. The method of Claim 1 wherein the plasma generating  
2 electrode is patterned and has at least one opening therein and wherein the exposed  
3 surface of the substrate is treated in a pattern corresponding to the patterned plasma  
4 generating electrode including the opening therein.

1           22. The method of Claim 1 wherein the selected gas is selected  
2 from the group consisting of nitrogen, oxygen, argon, sulfur hexafluoride, chlorine,  
3 and chlorofluorocarbons to treat the exposed surface of the substrate by etching it.

1           23. A method of plasma treatment of substrates comprising:  
2           (a) applying a dielectric layer on a substrate surface, the  
3 dielectric layer having at least one opening therein that exposes the substrate  
4 surface, and applying a plasma generating electrode to the dielectric layer adjacent  
5 to the opening in the dielectric layer and to the surface of the substrate exposed at  
6 the opening in the dielectric layer;

7           (b) establishing a selected pressure of a selected gas over the  
8 plasma generating electrode and the substrate surface; and

9           (c) applying a voltage to the plasma generating electrode to  
10 establish a plasma in the selected gas in a region between the electrode and the

11 adjacent exposed surface of the substrate for a selected period of time to plasma  
12 treat the substrate.

1               24. The method of Claim 23 wherein the plasma generating  
2 electrode comprises at least two separate electrode segments which are spaced from  
3 each other.

1               25. The method of Claim 23 wherein the gas pressure established  
2 over the substrate and electrode is greater than 1 torr.

1               26. The method of Claim 23 wherein the plasma generating  
2 electrode is spaced by the dielectric layer within 1,000 µm of the substrate surface.

1               27. The method of Claim 26 wherein the electrode is spaced less  
2 than 50 µm from the substrate surface.

1               28. The method of Claim 23 wherein the plasma is established by  
2 applying a DC voltage between the electrode and the substrate surface sufficient to  
3 generate a plasma in the region between the electrode and the substrate surface  
4 without arcing and to drawing positively charged ions toward the substrate surface.

1               29. The method of Claim 23 wherein the substrate is a silicon  
2 wafer, and wherein in the step of applying a voltage between the electrode and the  
3 substrate, a conductive plate is applied to the silicon wafer on a surface thereof  
4 opposite to the surface to be treated and a voltage source is connected to the  
5 electrode and the conductive plate to provide the voltage between the electrode and  
6 the substrate.

1               30. The method of Claim 23 wherein the step of positioning the  
2 plasma generating electrode comprises applying a dielectric layer having at least one  
3 opening therein on the substrate surface and applying the plasma generating  
4 electrode to the dielectric layer adjacent to the opening in the dielectric layer and  
5 adjacent to the surface of the substrate exposed by the dielectric layer.

1           31. The method of Claim 23 further including applying a second  
2 electrode on the substrate surface, which is between the dielectric layer and the  
3 substrate surface, and the step of applying voltage comprises applying voltage  
4 between the plasma generating electrode and the second electrode.

1           32. The method of Claim 23 including after applying a voltage to  
2 plasma treat the substrate for a selected period of time, removing the dielectric layer  
3 and the plasma generating electrode from the substance.

1           33. Apparatus for plasma treatment of substrates comprising:  
2               (a) a plasma generating electrode with a flat bottom surface;  
3               (b) a holder connected to the electrode to position the electrode  
4 bottom surface closely adjacent to and spaced from a surface of a substrate to within  
5 1,000  $\mu$ m or less;  
6               (c) a conductive connector to provide a conductive connection to  
7 the substrate to be treated; and  
8               (d) a voltage source connected to the electrode and the conductive  
9 connector to selectively provide a voltage between the electrode and the substrate  
10 surface to establish a plasma in regions between the electrode and the surface of the  
11 substrate.

1           34. The apparatus of Claim 33 wherein the conductive connector  
2 comprises a conductive plate having a surface on which the substrate rests with the  
3 surface thereof in contact with the conductive plate opposite to a surface of the  
4 substrate to be treated.

1           35. The apparatus of Claim 33 wherein the plasma generating  
2 electrode comprises at least two separate electrode segments which are spaced from  
3 each other.

1           36. The apparatus of Claim 33 further including a chamber  
2 enclosing the plasma generating electrode, the holder, the connector and the  
3 substrate to be treated and including a vacuum pump connected to the chamber and

4 a gas supply connected to the chamber to provide the selected gas to the chamber in  
5 which the plasma is to be established.

1 37. The apparatus of Claim 33 wherein the voltage source is a DC  
2 voltage source.

1 38. The apparatus of Claim 33 wherein the voltage source is an  
2 AC voltage source.

1 39. The apparatus of Claim 33 wherein the connector comprises a  
2 conductive electrode layer on the substrate surface.

1 40. Micro-plasma treatment apparatus comprising:  
2 (a) a substrate with a surface to be treated with a plasma;  
3 (b) a dielectric layer mounted on the surface of the substrate and  
4 having at least one opening therein that exposes the surface of the substrate at the  
5 opening; and  
6 (c) a plasma generating electrode mounted over the dielectric  
7 layer and spaced thereby from the substrate surface such that a plasma may be  
8 established between the electrode and the exposed surface of the substrate in the  
9 opening in the dielectric layer.

1 41. The apparatus of Claim 40 wherein the dielectric layer has a  
2 pattern of plural openings therein with the electrode extending over the openings.

1 42. The apparatus of Claim 40 wherein the electrode has an  
2 opening therein at the opening in the dielectric layer and further including a sealing  
3 layer over the electrode that covers the opening in the electrode and the dielectric  
4 layer to confine plasma to the regions defined by the opening in the dielectric layer.

1 43. The apparatus of Claim 40 wherein the electrode has an  
2 opening therein which coincides with the opening in the dielectric layer.

1 44. The apparatus of Claim 40 further including a conducting  
2 plate in contact with a surface of the substrate opposite to the surface to be treated,

3 a voltage source, and electrical connectors connected to the electrode and the  
4 conductive plate such that a voltage can be applied by the voltage source to the  
5 electrode and conductive plate to thereby provide an electric field in regions defined  
6 by the openings in the dielectric layer.

1               45. The apparatus of Claim 40 wherein the electrode has plural  
2 separated and electrically isolated segments and including voltage sources connected  
3 by electrical lines separately to each electrode segment to apply voltage thereto  
4 separately.

1               46. The apparatus of Claim 45 further including a conductive  
2 plate mounted in contact with a surface of the substrate opposite to the surface to be  
3 treated and wherein the voltage sources are connected to the conducting plate to  
4 apply voltages between the conducting plate and the electrode segments.

1               47. The apparatus of Claim 40 wherein the substrate comprises a  
2 silicon wafer.

1               48. The apparatus of Claim 40 including a DC voltage source  
2 connected to the electrode to provide a DC voltage to generate a plasma.

1               49. The apparatus of Claim 40 including an AC voltage source  
2 connected to the electrode to provide an AC voltage to generate a plasma.

1               50. The apparatus of Claim 40 further including a casing  
2 surrounding the substrate, dielectric layer, and electrode and sealing the same from  
3 the ambient atmosphere, and including electrical leads extending from the electrode  
4 and from electrical contact with the substrate to leads extending externally from the  
5 casing such that electrical voltage can be applied to the extending leads to  
6 selectively establish a plasma in the regions at the opening in the dielectric layer.

1               51. The apparatus of Claim 40 including a second electrode on the  
2 substrate surface and under the dielectric layer, the second electrode having at least  
3 one opening therein at the opening in the dielectric layer such that a voltage may be

4 applied between the electrodes to establish a plasma in the openings in the dielectric  
5 layer.

1 52. The apparatus of Claim 51 wherein the second electrode has a  
2 plurality of openings therein at the opening in the dielectric layer.

1 53. The apparatus of Claim 40 wherein the thickness of the  
2 dielectric layer is less than 1000  $\mu\text{m}$ .

1 54. The apparatus of Claim 40 including another dielectric layer  
2 with a second electrode thereon mounted on the surface of the substrate such that  
3 the second electrode is spaced from the plasma generating electrode with the  
4 exposed substrate surface lying between them, whereby a voltage may be applied  
5 between the plasma generating electrode and the second electrode for generating a  
6 plasma.

1 55. The apparatus of Claim 54 including bottom electrode layers  
2 on the substrate under the dielectric layers and the plasma generating electrode and  
3 the second electrode.

1 56. The apparatus of Claim 54 including at least one control  
2 electrode on the substrate surface between the plasma generating electrode and the  
3 second electrode and including a voltage source connected to the control electrode  
4 to selectively bias it.

1 57. The apparatus of Claim 56 wherein the control electrode has  
2 at least one opening therein that exposes the surface of the substrate.

1 58. A method of plasma treatment of substrates comprising:  
2 (a) positioning a plasma generating electrode adjacent to an  
3 exposed surface of a substrate wherein the electrode is positioned to be spaced  
4 within 1,000  $\mu\text{m}$  of the substrate surface;  
5 (b) establishing a selected pressure of a selected gas over the  
6 plasma generating electrode and the substrate surface; and

7                   (c) applying a voltage to the plasma generating electrode to  
8 establish a plasma in the selected gas that is localized in a region between the  
9 electrode and the adjacent exposed surface of the substrate for a selected period of  
10 time to plasma treat the substrate, wherein the gas pressure established over the  
11 substrate and electrode is at least 1 torr and the electrode is positioned sufficiently  
12 close to the substrate surface that the plasma is established by applying a voltage to  
13 the electrode at a voltage level that does not result in arcing.

1                   59. The method of Claim 58 wherein the electrode is spaced less  
2 than 50  $\mu$ m from the substrate surface.

1                   60. The method of Claim 58 wherein the plasma is established to  
2 remove material from the substrate.

1                   61. The method of Claim 58 wherein the plasma is established to  
2 remove material from the substrate.

1                   62. The method of Claim 58 wherein the plasma is established by  
2 applying a DC voltage between the electrode and the substrate surface sufficient to  
3 generate a plasma in the region between the electrode and the substrate surface  
4 without arcing and to draw positively charged ions toward the substrate surface.